NOVEMBER 1957

3
SUMMARY

of

THE DEVELOPMENT OF A SOIL MOISTURE PREDICTION METHOD

by

o o
Arthur W. Krumbach and Forest W. Stearns

3e
With

SUPPLEMENT CONSISTING OF A REVIEW OF REPORTS AND PUBLICATIONS
FROM NOVEMBER 1957 TO JUNE 1959

o
VICKSBURG RESEARCH CENTER
SOUTHERN FOREST EXPERIMENT STATION
WATERWAYS EXPERIMENT STATION
5a VICKSBURG, MISSISSIPPI

FOREWORD

963417

We hope to accomplish four things by summarizing the work completed to date by the Vicksburg Research Center. This work has consisted of developing a method of predicting soil moisture without contact with the soil. The work has been done for and in cooperation with the U. S. Engineers Army Mobility Research Center.

The first purpose is to afford our own staff a rapid means of review of past work. It will be used as a training aid in the orientation of new workers. For the older hands it will serve as a ready reference for reviewing certain phases of the work and will indicate the reports in which further information is available.

For our associates in the Corps of Engineers, and for other Forest Experiment Stations and Research Centers, we hope that this summary will provide a ready reference that will explain our program and the application of the work which we may have done together.

The Vicksburg research program is one of teamwork in research between the U. S. Engineers Army Mobility Research Center and the U. S. Forest Service Vicksburg Research Center. This program contains many features unique to the research programs both of the Engineers and the Forest Service. One of the purposes of this summary is to assist in explaining the program to visitors who are interested in our research program and the techniques which we have used.

Finally, the summary performs the task of tying together all of the work of the initial phase of our program, that of developing a method of soil moisture prediction. It would not be appropriate to make a publication of this work for most of it is already published. However, a summary which marks the end of the first phase of the program, that is, the development of a method of predicting soil moisture, will be helpful in orienting the present phase which consists of (a) improvement of soil moisture prediction, and (b) the combination of soil moisture prediction with strength prediction into a prediction of trafficability.

This summary was compiled and edited by Arthur W. Krumbach and Forest W. Stearns. It includes the work through 1956.

A supplement has been added which reviews the work that has been accomplished through June 1959.

Hubert D. Burke

HUBERT D. BURKE
Research Center Leader

INTRODUCTION

This paper summarizes the work conducted by the staff of the Vicksburg Research Center[1] from February 1951 until the present time. The work has comprised the development and testing of a method of soil moisture prediction for the surface to twelve inch depth. The purpose of this review is to assemble under one cover the highlights of the studies that have been accomplished and the procedures used. Further work by the Vicksburg Research Center will consist of refining the method reported herein and the development of soil moisture-strength relations and their application to military trafficability. The review is divided into two major sections as described below.

Part I presents the chronological development of the soil-moisture prediction method. The latest stage of the work has been the development of average moisture prediction relations for application without specific study of the soil moisture regime on the areas for which the prediction was made. The reports covering these developments are cited with brief abstracts of the contents of each. Annotated citations are given for office reports on nine areas in the continental United States and Alaska used in the development of the prediction method. The progress reports were prepared for limited distribution and the office reports are in manuscript form.

Part II includes a summary of special studies, primarily in methods and instruments, which were established to resolve some of the problems met in developing the method of soil moisture prediction. Some of these may be of general interest to other workers in soils and hydrology. This material has been published in Occasional Papers of the Southern Forest Experiment Station and in journals which are available for general use, and is therefore just highlighted here.

Publications covered in Part II are grouped in three categories: (1) Equipment and techniques for measurement of soil moisture; (2) Physical properties of soils; and (3) Soil moisture relations. Each category includes a brief introduction and an annotated bibliography.

The supplement consists of a summary of reports and publications completed since November 1957.

---

1 Prior to June 1957, the official title of the Vicksburg Research Center was the Vicksburg Infiltration Project

DEVELOPMENT OF THE SOIL MOISTURE PREDICTION METHOD

Three sites were established near Vicksburg in 1951 as a pilot study. The following data were taken on a daily basis; air and soil temperature and soil moisture, humidity, wind movement, pan evaporation, water table depth, and rainfall intensity and amount. Development and density of vegetation were checked periodically. Soil studies included profile descriptions, determination of texture, bulk density, plasticity, soil strength, and soil moisture-tension relations. The same procedures for taking data were followed closely throughout the succeeding phases of the study.

The goal of this initial study was to determine the daily march of soil moisture through the upper foot of the soil profile in relation to rainfall and other environmental factors.

From the beginning it was apparent that soil moisture prediction involved two processes, moisture accretion, and moisture depletion. Separate methods for predicting each had to be developed.

Accretion Prediction

It soon became evident that accretion in the 0 to 6 and 6 to 12 inch layers was governed by the amount of rainfall and the available storage space in the soil. These relationships formed the basis for accretion prediction. The basic assumption being: when rainfall was less than available storage, accretion would be dependent upon the amount of rainfall; when rainfall was greater than available storage, accretion would be dependent upon the amount of storage available.

This led to the formulation of two accretion classes:

> Class I: Total rainfall less than available storage in the 0 to 12 inch depth.
>
> Class II: Total rainfall equal to or greater than the available storage in the 0 to 12 inch layer.

The step-by-step procedure used for obtaining Class I and II accretion predictions from daily soil-moisture[1] and rainfall records is as follows:

"1. Tabulate the amount of precipitation for each storm and the moisture content on the day before and after each storm for the 0 to 6 and 6 to 12 inch layer.

1/ "In the Vicksburg studies moisture content is expressed in inches of water as follows:

$$\text{Moisture content, inches per 6 in.} = \frac{\text{moisture content, \% by weight x bulk density x 6}''}{\text{unit weight of water x 100}}$$

[illegible] [illegible] the actual moisture content.

3. For each storm, determine the amount of accretion in each layer as the [illegible] moisture content [illegible] small rains. Extended accretion following some storms may require adding accretion for second and third days.

4. Determine the minimum storm size for which accretion occurs, as follows: For storms less than 0.25 inches, retabulate the rainfall accretion for the two 6 inch layers into groups of 0.05 inches rainfall intervals starting with 0.00 - 0.04 inches, then 0.05 - 0.09 inches, etc. Determine average accretion per 6 inch depth for each group. The lower limit of the smallest rainfall group having positive accretion is the minimum storm size, considering both layers. Cross out all storms less than the minimum from the original storm tabulation. At the Vicksburg installation sites the minimum was a storm of 0.10 inches. At sites with a greater vegetal cover - and thus greater interception - the storm size with no accretion may be larger.

5. Classify accretion from remaining storms in Class I or II.

6. Plot the data for each accretion class by 6 inch layers, estimating accretion relations by linear regressions as follows:2/

Class I: Horizontal scale, rainfall
Vertical scale, accretion.

Class II: Horizontal scale, available storage
Vertical scale, accretion."

Additional work on accretion led to the following general conclusions:

a. Season of the year had little effect upon accretion. Therefore, Class I and II accretions were derived from, and applied to, an annual record regardless of season.

b. Because the study was concerned only with the retention of water in the surface foot, the amount lost by runoff and by percolation through the surface foot were variables of secondary importance.

c. Such things as interception of rainfall by vegetation are automatically incorporated in the regression of accretion on available storage or rainfall.

d. If reliable accretion relations are to be derived, measurement of soil moisture must be made before and after storms.

1/ "Field maximum moisture content is defined as the highest recurring average moisture content measured during the period of record."

2/ "Typical regressions for Class I and Class II storms are shown in Fig.

Depletion Prediction

Depletion is the amount of water loss in a given soil layer over a period of time. This moisture loss results from both evapotranspiration and drainage. Soil moisture depletion rates vary seasonally; summer rates are higher than winter. It was found that three curves were necessary for each 6 inch layer a summer curve, a winter curve, and a transition curve used for both autumn and spring.

Depletion curves were plotted from daily soil-moisture records as follows:

1. Periods of the moisture record were selected in which summer or winter conditions were known to exist. Summer is the growing season with high temperatures and rapid depletion, and winter is the dormant season with low temperatures and slow depletion.

2. Graph-tracing paper was placed as an overlay on the chart of daily moisture contents. Choosing a given season, a depletion period was traced on the overlay. A long period starting at a high moisture content is preferable.

3. The overlay was moved horizontally to another depletion period so that the second period coincided as closely as possible with the traced curve. The second curve was traced.

4. The process was repeated so that a family of curves was traced extending throughout the soil-moisture range. (Figure 2)

5. A freehand curve was drawn on a graph paper overlay through the family of curves.

6. Steps 2 through 5 were repeated for summer and winter seasons of each layer.

7. The summer and winter derived curves were laid on the graph of daily moisture content for the proper layer. The overlays were moved horizontally to determine the dates at which the slope of the curve (depletion rate) changed during the months bordering the summer and winter seasons. Four dates for each year of record were determined which separated the summer, spring-autumn and winter depletion periods[4].

8. Following steps 2 through 5, a family of curves was traced for both autumn and spring transition periods, one family for each depth. The best curve was drawn through the family on the overlay (Figure 2). Minor deviations from the trend were ignored.

9. Derived depletion curves were extended at the wet end to the

---

4/ "These dates are referred to as transition dates and are defined as 'A date at which the average depletion rate exhibits a distinct change as shown in the plot of the daily soil moisture record. Four dates are posted per year corresponding to, but not coinciding with, calendar season dates'."

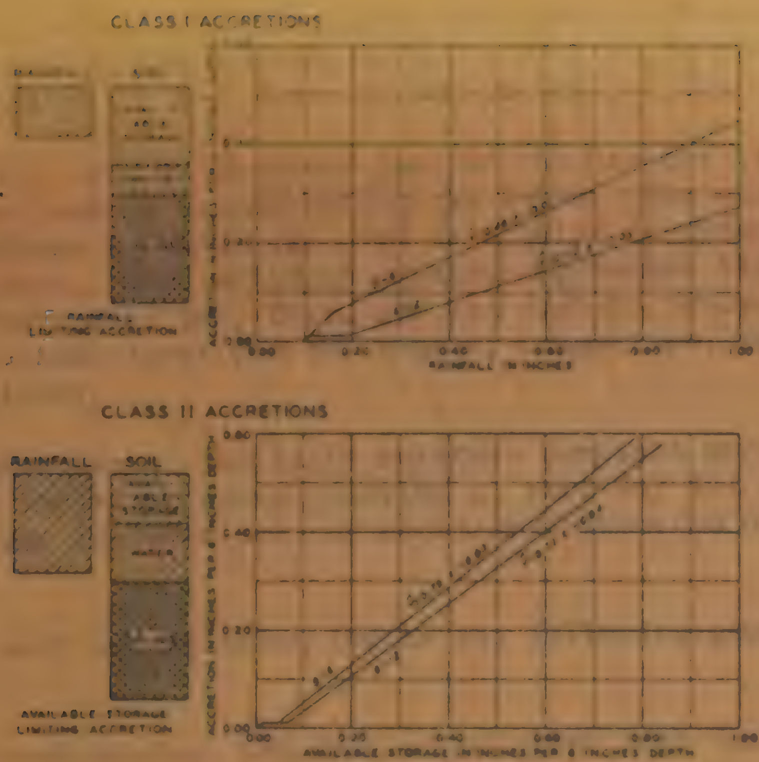


Fig. 1. Typical regressions for Class I and Class II accretions in Commerce silty clay

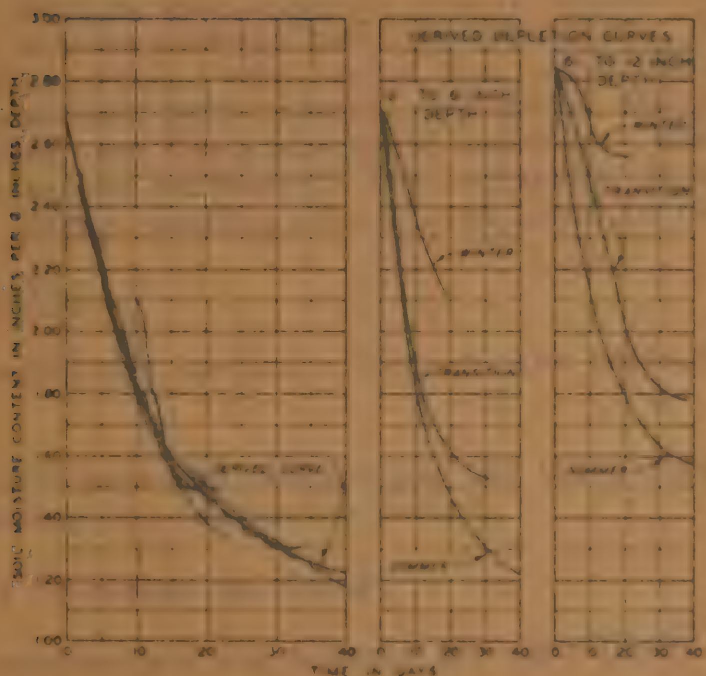


Fig. 2. Left: Derivation of a typical depletion curve from a family of 8 actual summer depletion curves. Right: Seasonal depletion curves, Commerce silty clay

moisture maxima that occurred throughout the period of record. The curves were extended to the maximum moisture over an interval of one to several days, considering the slope at the wet end of the curves.

10. The daily rate of moisture loss at the dry end of the curve was calculated for use in extrapolating the curve. The wilting point value (15-atmospheres tension) was used as a guide in reducing the daily rate of loss to zero. When moisture content approached the wilting point, it required approximately two, five, and ten days to remove 0.10 inches water from each 6 inch layer for the summer, transition, and winter seasons, respectively.

11. For convenience, the daily moisture contents were tabulated from the average depletion curve starting at zero day for each season and layer. Step 10 was included for any necessary extension of the depletion period.

Additional work on depletion led to the following general conclusions:

a. Within each season, the rate of moisture loss was essentially similar for several drying cycles at comparable moisture levels for a given site. Daily variation in pan evaporation, humidity, wind and cloud cover when tested individually did not correlate with the variation in moisture loss.

b. On some sites, the measurement of moisture content did not extend through a wide enough range to develop depletion relations. In such cases, artificial wetting was attempted (i.e., Montana and New Mexico) so that data on soil moisture levels could be augmented. Depletion rates following artificial wetting were faster than under natural conditions because of lateral movement into adjacent dry areas, the presence of roots from adjoining areas, and low atmospheric humidity. Hence, depletion during these periods was excluded in the derivation of depletion curves; drying following natural wetting only was included in the curves.

Making the Prediction

To predict daily soil-moisture content, the following information is needed:

1. Actual soil moisture content for the two 6-inch layers on the day starting the prediction period.

2. Rainfall by storms and dates.

3. Field maximum moisture content for each layer[2/].

4. Derived depletion and accretion relations.

5. Minimum storm size.

6. Transition dates.

The steps in prediction are as follows:

1. Start with the known moisture contents of the first day of record.

2. For each succeeding day with no storm, the predicted moisture content is determined from the depletion table. The table is entered on the known moisture content, and the moisture content interpolated and recorded for successive daily intervals.

3. On the occurrence of a storm, the antecedent available storage is determined for each 6 inch layer by subtracting the predicted moisture content of the day before the storm from the maximum moisture content.

4. The accretion class is then selected.

5. The predicted accretion in each layer is read from the accretion graphs. For each storm, the predicted available storage, accretion class, and accretion are recorded.

6. The accretions are added to the moisture contents of the day before the storm to give the moisture contents following the storm for each depth.

7. Storms less than the minimum size are ignored; the predicted moisture content is determined from the depletion curves, assuming in effect, that on days with those small storms, no rain fell and normal depletion occurred.

8. If the moisture prediction between storms extends to low moisture contents beyond the depletion curve, use the daily rate of loss determined for the dry end in predicting succeeding moisture contents.

9. When a transition date is reached, change to the next seasonal depletion curve to continue the prediction even though the change occurs during a depletion period. The accretion relations are the same throughout the year.

In some areas high water-tables will affect the soil moisture relations. A long range soil moisture prediction, especially during the wet months, will require consideration of water table depths. As long as the water table is within 12 inches of the surface the soil moisture of the surface to 12 inch depth was assumed to remain constant. When the water table drops below this depth, normal accretion and depletion relations were used with a correction for high water. A sample prediction is illustrated in Table 1, with data from Mound, Louisiana site.

Table 1

SAMPLE PREDICTION OF SOIL-MOISTURE CONTENT
FOR A POORLY DRAINED CONGAREE SILTY CLAY AT [illegible] ([illegible]) SITE

Apr 1952	Moisture Content, in. 0- to 6-in. Depth	Moisture Content, in. 6- to 12-in. Depth	May 1952	Moisture Content, in. 0- to 6-in. Depth	Moisture Content, in. 6- to 12-in. Depth
	2.71*	2.85*			
15	2.26**	2.68**	1	1.85	2.42
16	2.18	2.65	2 R	1.80	2.37
17	2.08	2.62	3	2.20	2.60
18	1.99	2.58	4	2.10	2.56
19	1.91	2.54	5	2.01	2.52
20 R	1.85	2.50	6	1.93	2.48
21 R	1.93	2.51	7	1.87	2.44
22 R	1.97	2.52	8	1.82	2.40
23	2.53	2.72	9 R	1.78	2.35
24	2.41	2.68	S 10 R	1.72	2.30
25	2.33	2.65	11	1.81	2.32
26	2.25	2.62	12	1.76	2.27
27	2.16	2.58	13	1.70	2.22
28	2.06	2.54	14	1.64	2.16
29	1.98	2.50	15	1.61	2.10
30	1.91	2.46			

DETERMINATION OF ACCRETION AMOUNTS FOR USE WITH ABOVE DATA

Date	Amt of Rain	Available Storage, in. 0- to 6-in. Depth	Available Storage, in. 6- to 12-in. Depth	Accretion Class	Accretion, in. 0- to 6-in. Depth	Accretion, in. 6- to 12-in. Depth
4/20	0.19	0.86	0.35	I	0.08	0.01
4/21	0.12	0.78	0.34	I	0.04	0.01
4/22	1.21	0.74	0.33	II	0.56	0.20
5/2	0.89	0.91	0.48	I	0.40	0.23
5/9	0.05	- - - - - - -	Below Minimum	Storm Size	- - - - - - -	
5/10	0.22	0.99	0.55	I	0.09	0.02

* - Field-maximum moisture contents.
** - Actual values to start the prediction
R - Occurrence of rainfall.
S - Beginning of summer season.

Extension of Prediction Studies

In 1953, field work was extended using Vicksburg trained personnel for field studies in Idaho, Minnesota, Arkansas, Colorado, and New Mexico where year-long observations were undertaken. Additional sites were added in Washington, Montana, and Alaska in 1954, and in Puerto Rico in 1955.

Accuracy of Prediction

Comparisons of predicted versus actual moisture content showed variation of 0.06 to 0.13 inches for the 0 - 6 inch layer, and 0.06 to 0.12 inches for the 6- 12 inch layer when the soil moisture contents, as determined by the prediction relations, were compared to the same soil-moisture record that was used to develop the relations.

Deviations in the predictions made for the second year using relations from the first year were usually not much greater than those for the derivation period. However, the results indicate that if weather conditions vary greatly from one year to the next, prediction relationships are liable to be poor.

Development of Tentative Average Relations

One of the main objectives of these studies was to be able to predict moisture for a given area without having to make actual physical measurements. Hence, the next phase of the prediction method was the development of "Tentative Average Relations" which could be applied to an area without previous detailed study of that area. The average factors and relations developed, based on the previous prediction studies, were field maximum moisture content, field minimum moisture contents 3/, and moisture depletion and accretion rates by seasons.

These had to be developed with consideration of various kinds of soils, climate, vegetation, and topographic and geographic position. If soil and site characteristics are known, soil moisture may be predicted. At the present stage of development it must be recognized that the prediction contains large errors; these are particularly evident on wet soils.

Approximation of Field Maximum Moisture Content

Six factors were plotted against field maximum moisture content to determine the best approximation: wetness index, (Table 1); sand content; clay content; per cent organic matter; bulk density; and 0.06-atmosphere tension values.

The 0.06 atmosphere tension values give the best correlation for a single value. Better correlations were obtained with a combination of variables, including tension. To facilitate field use, equations were set up based on texture, organic matter and wetness index without including tension. The factor for organic matter proved larger in the 0 to 6 inch layer, while in the 6 to 12 inch layer, the clay factor was larger. This is also true in relation to the field minimum. (Table 3)

3/ "The lowest value of each depletion curve, representing an average of the lowest moisture levels that occurred."

Table 2

CLASSIFICATION OF SITES BY WETNESS INDEX

Wetness Index	Potential Wetness	Depth to Water Table	Depth of Wetting	*General Characteristics of Sites
0	Arid	Indeterminable	Less than 1 Foot	Located in desert regions.
1	Dry	Indeterminable	1-4 Feet	Steeply sloping, denuded, or severely eroded and gullied.
[illegible]	Average	More than 4 Feet	More than 4 Feet	Well drained soil with no restricted layers or pans, fair to good internal and external drainage. Slope may be flat to steep.
[illegible]	Wet	1-4 Feet	To water-table	Not well drained soil. Restricted layers or deep pans may be present. May occur at base of slopes, on terraces, upland flats or bottom lands.
4	Saturated	Less than 1 Foot	To water-table	Waterlogged or flooded sites at least part of year. Bottom lands subject to frequent overflow. Upland flats with poor internal drainage or shallow pans. Slopes with very poor internal drainage.

* For use in classification when water-table and wetting depths are not known.

Table 3

EQUATIONS FOR APPROXIMATING FIELD MAXIMUM AND MINIMUM SOIL MOISTURE CONTENTS

Field Maximum

Surface to 6 inch layer = 2.06 - 0.011S + 0.116 Om + 0.151 WI
6 to 12 inch layer = 2.06 - 0.012S + 0.008C + 0.155 WI

Field Minimum

Surface to 6 inch layer = -0.013 + 0.007C + 0.074 Om + 0.149 WI
6 to 12 inch layer = 0.131 + 0.017C + 0.064 Om + 0.119 WI

When S is percent sand, C is percent clay, Om is percent organic matter, WI is wetness index.

Approximation of the Field Minimum Moisture Content

The minimum moisture value was based upon soil properties that determine water retention under high stress, thus the factors used in determining these equations were texture, organic matter, and wetness index.

Approximation of Minimum Storm Size

A minimum storm size of 0.10 inches was used as 84% of the sites showed a minimum of 0.10 inches or less.

Development of Average Accretion Relationships

Regressions developed for average accretion relationships are:

Storm Size	Surface to 6-in. Layer	6 to 12-in. Layer
Class I	$Y = 0.47X - 0.01$	$Y = 0.22X - 0.01$
Class II	$Y = 0.75Z - 0.05$	$Y = 0.60Z - 0.02$

Where Y = prediction accretion
X = rainfall
Z = available storage at the start of the storm

Individual accretion curves were also developed for sand, silt, and clay soils. These curves did not differ appreciable from the average curves, hence no allowance was made for soil texture in routine accretion predictions.

Development of Transition Dates

Insufficient data were gathered to develop an accurate means of prediction of transition dates, and a table of dates was established empirically from observations at the various sites.

Development of Average Depletion Relations

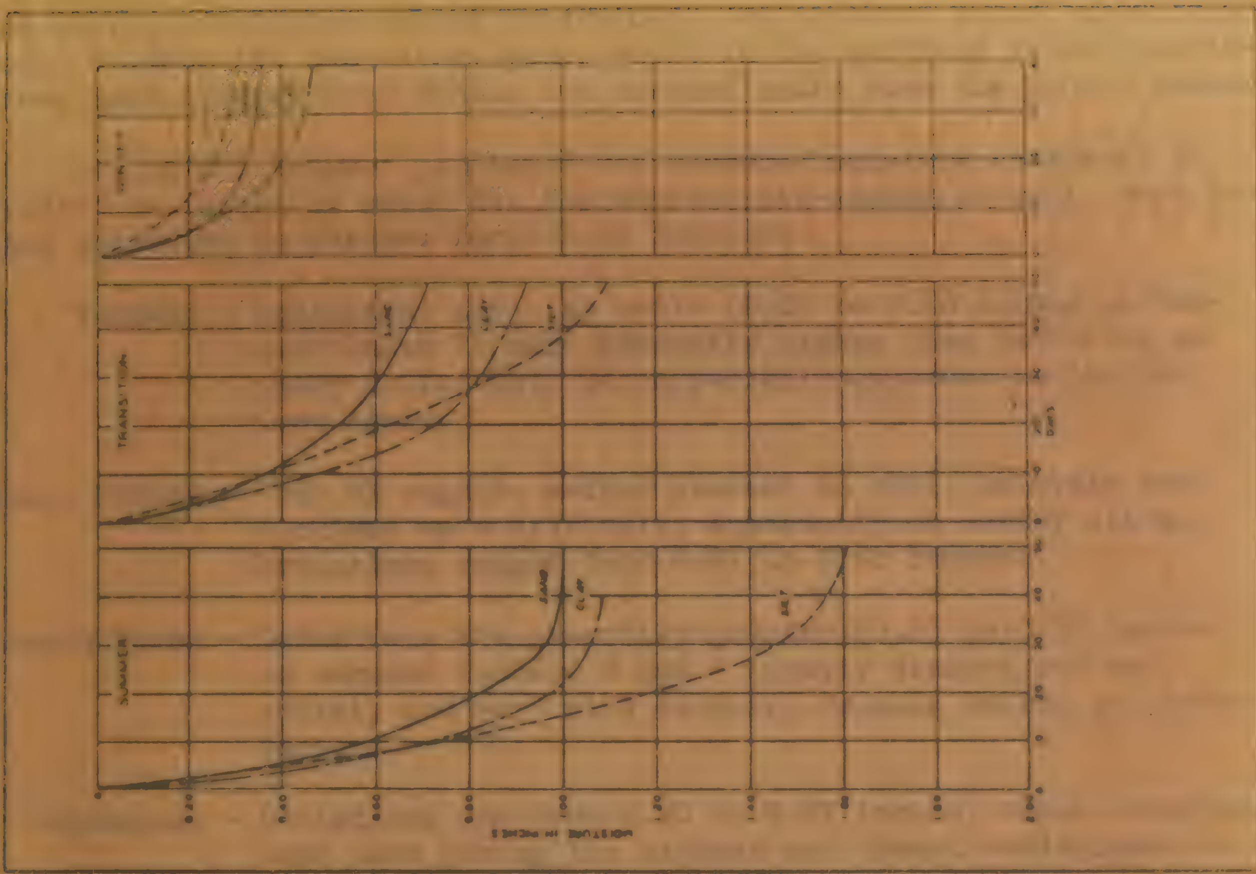
In the early stages of analyzing depletion curves, three distinct segments of the curve were noted: first, rapid depletion including water lost by gravity flow, second, a uniform rate from evapotranspiration losses alone, and third, a reduced rate from evapotranspiration losses at low soil moisture content.

Because texture influences maximum and minimum estimations, and because it influences drainage and availability of water, curves were grouped into three textural classes, sand, silt, and clay, Figure 3.

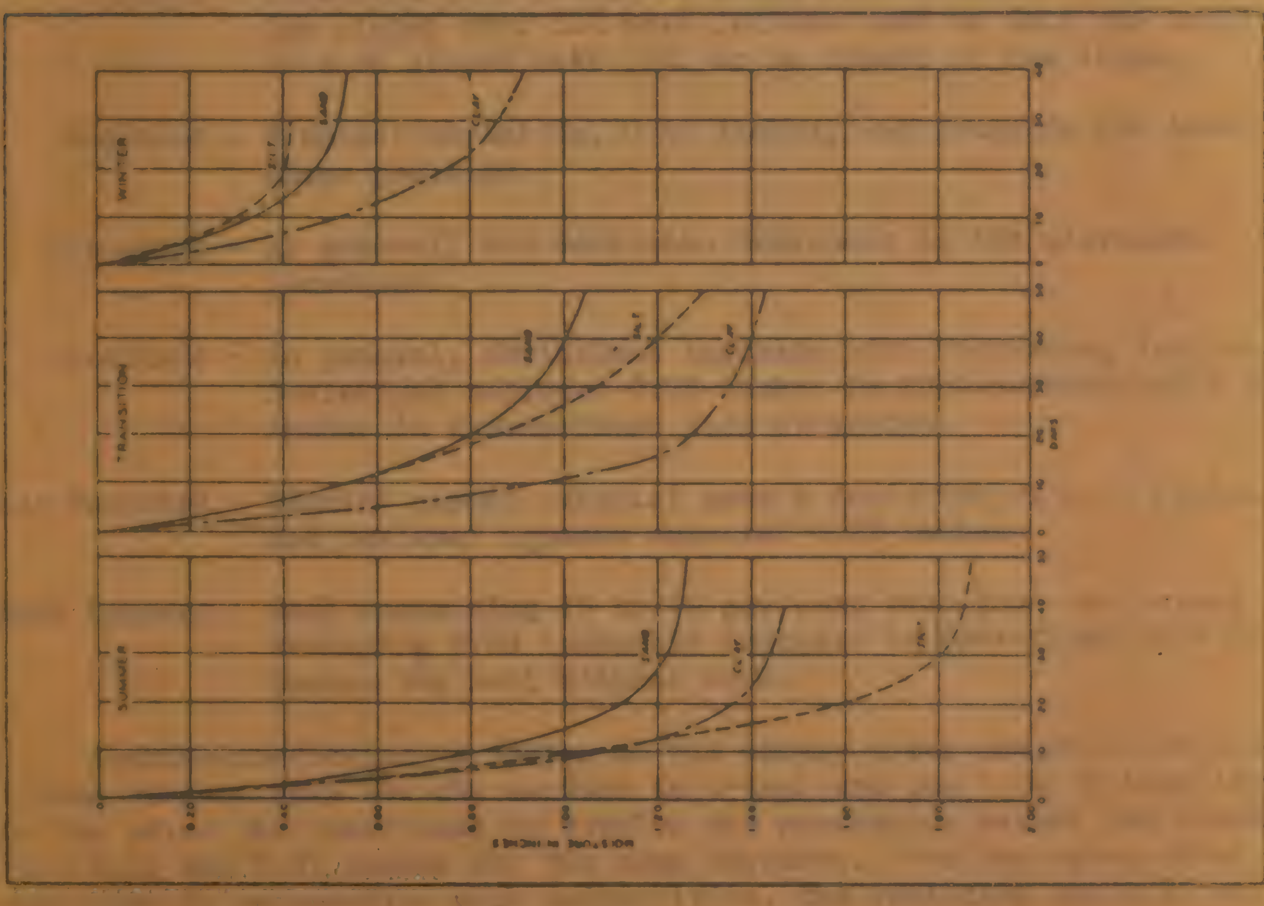
Tentative average depletion tables were developed from these curves for each of the textural classes.

Results of Application of Tentative Average Relations

Throughout the United States and Alaska, 651 sites were selected, and the tentative average relations were applied for a period of one year. Field maximum and field minimum moisture contents were calculated. A minimum storm size of 0.10 inches was used, transition dates were selected,



6- to 12-in. layer



0- to 6-in. layer

Fig. 3. Curves showing average moisture loss from field maximum

and average depletion tables determined. On southern sites, predictions could be made for the entire year, while in the northern sites, predictions were stopped over winter and started again when the ground thawed.

Deviations between predicted and measured moisture contents, expressed as inches of water for the surface six-inches of soil, were averaged according to various factors as follows:

Texture - Deviations for clay soils (0.30 to 0.48 inches at Wetness Index 2) were generally higher than for silts or sandy soils; this was especially apparent in the 0-6 inch layer.

Organic Matter - With 4% organic matter present in soil, accurate predictions were difficult, especially on wetter sites. Deviations ranged from 0.31 to 0.60 inches.

Wetness Index - Deviations are generally greater (0.25 to 0.55 inches) at wetness indices 3 and 4 (poorly drained and wet soils), and vary with texture, organic matter and other factors.

Vegetation - Deviations ran from 0.20 to 0.92 inches; shrub cover and bare land giving the highest and lowest deviations respectively.

Slope - Deviation as a result of slope proved small. However, few slopes over 10% were included and no data was available on slopes over 35%, or on aspect of the slope.

Position - Greatest deviation, 0.42 inches, was found in the lower slope position.

Elevation - In general, the deviation decreases as the elevation increases.

Latitude - In general, deviations increase with increasing latitude. Deviations averaged 0.29 inches in the southern and 0.39 inches in the northern tier of states.

Parent Material - Glacial parent material gave a deviation of 0.38 inches, and residual igneous material 0.22 inches.

Rock Content - Soil containing 16 to 40 per cent rock gave deviations averaging 0.40 inches in contrast to deviations of 0.33 inches for soil without rock.

Average prediction variation on the survey sites was 0.33 and 0.31 inches respectively for the surface to 6-inch and the 6 to 12 inch layer. On the sites that were used to develop the prediction method the averages were 0.25 and 0.22 inches for the same horizons. For ten other sites established in cooperation with universities, the variation was 0.33 and 0.32 inches, respectively.

The average relations can thus be used with a reasonable degree of accuracy for well drained sites, but the accuracy for poorly drained and wet sites is low.

LITERATURE PERTAINING TO THE DEVELOPMENT OF THE PREDICTION METHOD

<u>Progress Reports</u>

Dortignac, E. J., and Lull, H. W.

1951 A progress report on the development of methods for predicting soil moisture content. U. S. Forest Service, U.S.D.A., Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi. Vol. 1 - 40 pages, graphs and tables; Vol. II - 148 pages, graphs and tables.

Volume I is concerned solely with the development of methods for predicting soil moisture content on the Loring-Grenada-Collins silt loams and commerce clay at the Park, Rifle, and Mound sites. These sites, all within a few miles of Vicksburg, were studied from April through September 1951.

Volume II contains a history of the experimental areas, installation of the field equipment, a climatic summary, soil descriptions, vegetation and phenology, data from and procedures used in the water well studies, infiltration, bulk density, soil moisture tension, relationships, development of Colman unit curves, and methods for prediction of soil moisture accretion and depletion. The factors involved in soil-moisture depletion are discussed.

Staff, Vicksburg Infiltration Project

1952 The development of methods for predicting soil moisture content, progress report II, Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, 169 pages, including graphs and tables.

This report covers the winter period from October 1951 to March 1952 for the Park, Rifle, and Mound sites. Winter depletion and accretion curves are presented, special studies of methods are summarized and summer depletion is discussed further. Moisture prediction combining accretion and depletion is demonstrated.

Staff, Waterways Experiment Station and Vicksburg Infiltration Project

1954 Forecasting Trafficability of Soils. Report number 3. The Development of Methods for Predicting Soil Moisture Content. U. S. Forest Service, U.S.D.A., and Waterways Experiment Station, Corps of Engineers, U. S. Army., Vol. I - 31 Pages, Vol. II - 159 Pages, Vol. III - 155 pages, Appendix - 20 pages of text, and two tables, 77 and 151 pages each.

Volume I is a summary and comparison of the prediction methods covered in the previous reports, an account of the work in progress, and plans for future studies.

Volume II contains a description of the prediction method and of the experimental procedures used at Vicksburg. Illustrative data and curves presented earlier are included. The influence of vegetation on soil moisture loss is illustrated and discussed.

Volume III describes the prediction method developed by the Forest Service for other areas: a Vicksburg project at Laurel, Mississippi; Forest Experiment Station sites in Pennsylvania, South Carolina, and California; and Soil Conservation Service sites in Mississippi. Results of correlation studies are included, as well as a description of the prediction system of the Trafficability Section of the Waterways Experiment Station engineering staff.

The Appendix gives the results of special studies, and basic soil-moisture and weather data. The special studies are concerned with the following subjects; soil moisture measurement, core sampler for use with the air picnometer, use of radio-active materials, bulk density, infiltration, evapotranspiration, and soil moisture variation. Weather and soil data are restricted to sites in the Vicksburg area.

Carlson, C.A., and Horton, J. S.

1957 Forecasting trafficability of soil, Report No. 4. Information for predicting moisture in the surface foot of various soils. Technical memorandum No. 3-331. Waterways Experiment Station, Corps of Engineers, U.S. Army, Vicksburg, Mississippi, 80 pages of text, and nine tables.

This report reviews pertinent material from previous reports and presents, in concise form, the information about the soils and sites used to date in the development of the prediction method, and in the derivation of additional prediction relations. Soils-strength data are presented for 71 sites. The derived accretion and depletion relations are summarized for all sites and the accuracy of prediction at the various sites using the data from those sites is indicated.

Carlson, C.A., and Horton, J.S.

1957 Forecasting trafficability of soils, Report No. 5. Development and testing of some average relations for predicting soil moisture. Technical Memorandum No. 3-331, Waterways Experiment Station, Corps of Engineers, U.S. Army, Vicksburg, Mississippi. (Unpublished report now being processed)

Average moisture relations were developed from previous studies. These values were used to predict moisture on 651 sites throughout the United States and Alaska. Comparison of predicted values with actual moisture values for each site was made.

It was found that the prediction system applied to drained sites gave results within acceptable limits of accuracy.

Prediction on wet soils, and soils with high organic matter content needs to be improved. Prediction for clay soils, is also difficult. Rainfall and available storage were sufficient for development of tentative accretion relations expressed in linear regression formulae. Depletion curves for the summer, winter, and transition periods were developed by layers and textural groups.

On the average, predicted values derived from tentative average relations deviated from actual moisture content by 0.33 inches of water for the 0-6 inch layer, and 0.22 inches for the 6-12 inch layer. Tentative average relations are discussed and a sample application of the prediction method is provided. Descriptions of soil, strength-moisture relations and a discussion of runoff in relation to soil moisture prediction are included. The report also presents problems concerned with variation in soil moisture on a site and establishment of transition dates.

Reports on Prediction Development Sites

Most of the reports listed in this section are classed as office reports and exist only in manuscript form. They contain the data on which further development of the prediction method was based and tested.

These reports comprise information for each study area including descriptions of the soil, vegetation, geology and physiography; results of soil analyses; daily measurements of meteorological factors and of soil moisture and temperature. Analyses of accretion and depletion relationships were made for each area. These are included in the reports as are comparisons of the results of soil-moisture prediction with actual measured soil moisture.

In order to determine accuracy of the soil moisture prediction method, predicted values were compared to actual values. The only values available for testing the method were the values from which predicted values were originally determined. The comparison provides an estimate of prediction errors, and shows primarily how well the prediction relations express average conditions at a site during the period of measurement.

At other sites where prediction relations were tested on a subsequent year's data, substantially the same results were obtained wherever the climatic record of the two years was relatively similar.

Boyd, Raymond J.

1955 The development of methods for predicting soil moisture content. Office report on the Rockford, Washington Study. 111 pp.

This study was conducted in the Palouse wheat country near Rockford, Washington from February 1 to October 20, 1954. Five sites were studied on silt loams of three soil series. The valley site on Caldwell silt loam with a cover of permanent pasture was the only site influenced by a true water table. The Forest site on Couse silt loam had a cover of 30-40 year-old Ponderosa pine. On an eroded phase of the same Couse silt loam there was a site with a stand of winter wheat. The Wheat site, also supporting a stand of winter wheat, was located on an intergrade between the Palouse and Thatuna silt loams. The Fallow site immediately adjoining the Wheat site was kept bare during the period of study.

Rainfall was less than normal during the spring period and considerably above normal in August. Low rainfall resulted in somewhat fragmentary depletion curves. Artificial wetting was necessary to obtain data for soil strength tests. The Couse soil had relatively low infiltration capacity and proved difficult to wet to the 1-foot depth. Soil cracking occurred at Couse, Fallow and Wheat sites with cracks extending to a depth of 4-5 inches and may have resulted in greater accretion at the lower depths than was indicated by soil moisture units.

Depletion at the Fallow site was not as great as at the other sites during the summer season but differences were not marked during the remainder of the year.

Average deviation of observed from estimated soil moisture values for the 0-6 and 6-12 inch layers for all sites was 0.07 inch of moisture.

Broadfoot, W.M., and Carlson, C.A.

1954 Office report on a pilot survey of strength and moisture on Mississippi soils. Vicksburg Infiltration Project, Southern Forest Experiment Station, 9 pp., graphs and tables.

In order to determine procedures for securing field data, and to test the feasibility of using these data in soil strength and moisture predictions, a pilot survey was conducted in February and March 1954 on some of the principal soils in Mississippi.

The results of the pilot survey show:

(1) The methods of site selection, of the soil sampling techniques, and of the field and laboratory measures were satisfactory, and could be used with some modifications to fit local conditions and objectives, as the basis of future operations of this nature.

(2) Soil moisture prediction results were very encouraging in that with limited data on soil and site characteristics plus a rainfall record at nearby weather stations, a reasonable estimate of moisture was made for a number of soils over a relatively large area.

Soil data necessary for prediction included measured sand and clay content, estimated site wetness index (see page 9) and calculated pore space. Transition dates were estimated based on changes observed at the latitude of Vicksburg.

Predictions were checked with actual samples from which soil moisture and soil strength data were obtained.

Doss, Basil D., and Jones, Beryl, O.

1954 The development of methods for predicting soil moisture content. Office report on the Delta, Colorado study. 71 pp., 52 tables.

Work was carried on from June 1, 1953 to June 1, 1954 at 17 sites on the west and south sides and on top of Grand Mesa near Delta, Colorado. Soil moisture was measured with fiberglas units on a daily basis at four sites. Direct gravimetric samples were taken weekly at the other fifteen. Sites ranged in elevation from 5,150 to 10,460 feet. Vegetation types ranged through desert shad scale, pinyon-juniper, sage brush-grass, oakbush, aspen, open bog, and spruce-fir forest. Five bare areas were included. Parent material at all sites was classed as basalt or a mixture of basalt, shale, and alluvium.

"Typical differences in accretion and depletion relations at vegetated and bare sites are illustrated by the East Mesa data. Accretion was slightly higher at the vegetated site. The major difference, however, was in the depletion relations; rates were much higher for the vegetated site. During the depletion period from August 11 to 23 the vegetated site depleted 0.37 inch in the 0-6 inch layer and 0.24 inch in the 6-12 inch layer. During the same period the bare site depleted 0.11 and 0.00 inch at corresponding depths."

This report includes studies of infiltration tests in the Badger Wash area, a desert watershed with silt and clay loam soils and sparse grass and shrub vegetation, at about 5000 feet elevation.

A dry infiltration run was made at each site followed a day later by a wet run. Each run lasted 30 minutes and rainfall was applied at the rate of 5 inches per hour. Gravimetric sampling was used to determine soil moisture before and after runs. Infiltration rates for the soils derived from sandstone were approximately 3-5 times as great (2.68 in/hr for a dry run) as for the shale or mixed shale and sandstone soils. Mixed soils have a slightly higher infiltration rate than the shale soils. (0.80 and 0.68 inches per hour on dry run, respectively).

Depletion rates were determined for these soils for the fall period, and were found to be similar for the shale and mixed soils and slightly higher for the sandstone soils.

In the shale and limestone soils, accretion from 4.12 inches of artificial rainfall averaged 0.50 inches in the 0-6 inch layer and 0.14 inches in the 6-12 inch layer.

Helmers, Austin E.

1953 The development of methods for predicting soil moisture content. Office report on the Priest River, Idaho study. 135 pp.

Studies were conducted near the Priest River Experimental Forest in northern Idaho from June to November 1952 and April to August 1953. All study areas were located on bottomland soils, the Burn and Timber sites on light colored, well drained, silt loams, and the Lake, Benton, and Meadow sites on dark colored, poorly drained soils, an alluvial silt loam, a grey silt loam and a sedge peat respectively. Vegetation included (1) old-growth forest of western hemlock and other conifers (Timber Site), (2) a burned (1935 prescribed burn) area with planted ponderosa pine and natural

regeneration of cottonwood, larch and western white pine, ([illegible] Site), (3) a 90-year old stand of western white pine and western larch (Timber Site), (4) dense grass and forb meadow, previously pastured (Meadow Site) and (5) a dense stand of sedges (Lake Site).

Spring and summer depletion rates were derived. Spring depletion rates were found to be applicable until or into July. Artificial rainfall was used during the late summer and fall to develop accretion and depletion relationships. Summer rates (approximately 2 inches of water in 50 days) held into October or November while a short period of transition was indicated in late fall and early spring. However, this data derived using artificial wetting, proved to be unreliable both as to the transition dates noted and the accretion and depletion relations. Curves and dates were later revised for testing of the prediction method. The fall season proved to be particularly dry and was the only abnormal season. Ground water relationships were considered in prediction at the Lake site. There in the 6-12 inch layer, the depth to water table dropped from the 1 foot depth to the 2 foot depth between mid July and October 1.

Helmers, A.E., and Boyd, R. J.

1954 The development of methods for predicting soil moisture content. Office report on the Miles City, Montana study. 59 pp.

Studies were carried out on the U. S. Range Livestock Experiment Station, Miles City, Montana from April to August 1954. Three sites were located on native range land which had been previously grazed. River site, on a silty clay loam, supported a mixture of blue stem, wheat grass, sweet clover, and weeds. Highway site, on a silt loam, had a light cover of sand dropseed. Gumbo site, on a heavy clay, had a sparse cover of weeds and wheat grass. Some soil cracking was observed.

Infiltration rates were lower on the heavy Gumbo soil, than those measured on the River and Highway sites. Both spring and summer depletion rates level off sooner on the Gumbo site than on the other two. The Gumbo site is also different in that during early June it showed a high depletion rate in the 0-6 inch layer, (1 inch per 10 days), compared to the rate on the same site during May or July (approx. 0.5 inch in 10 days). This high rate is comparable with the summer rate on the other sites. The explanation appears to be in the nature of the vegetation. Gumbo supported a stand of short annual weeds which were at their most active period of growth during June whereas the River and Highway sites supported perennial grasses and forbs.

Mean deviations of predicted from actual moisture content were relatively low ranging from 0.05 to 0.13 inches. An unusually cold spell in late April and early May resulted in the only pronounced deviation. Separate spring and summer depletion relationships were found, with spring rates applicable through May, and summer rates June through August. None of the sites were wet enough to reach the expected field maximum so depletion curves were fragmentary.

[illegible], Ralph C.

1954 The development of methods for predicting soil moisture content. Office report on the Crossett, Arkansas study. 143 pp.

Seven sites were studied near Crossett, Arkansas from April 1, 1953, through to April 1, 1954. Six were located on silt loams and one (Sandy) on a fine sandy loam.

One of the silt loam sites (Headquarters) had a cover of mixed pine and hardwood, and another a mixture of grasses and forbs (Prairie). A bare site was established adjacent to each. The Sandy site was forested with a mixture of pine and hardwood while the remaining two sites ([illegible] and Brushy Creek) had a cover of mixed hardwoods.

In Class II, accretion relations (where rainfall equals or exceeds available storage) there is considerable variation. Headquarters and Brushy Creek sites accrete normally with 30 to 80% of the available storage filled. Sandy site, located on a low area subject to runoff from adjacent land and with higher permeability accreted close to 100% of available storage. [illegible] and Prairie sites showed low accretion relations apparently as a result of low permeability due in turn to a small amount of large pore space in the surface layers.

Rainfall during the study year was abnormal, excessively high in the spring and low during late summer and fall. Soils on these sites proved to have exceptionally low permeability rates, moisture would stand on the surface for hours even when soil moisture content was low. Perched water tables and heavy spring rains obscured the shift from winter to spring rates and drought obscured the autumn transition period. Deviations of predicted from observed moisture contents averaged 0.11 and 0.06 inch in the 0-6 and 6-12 inch depths respectively.

Soil temperature readings at Headquarters Bare and Prairie Herbaceous and Bare sites proved to be 10° F. higher at the 1-1/2 inch depth than at sites protected by a tree canopy.

As anticipated, the bare sites showed a lower summer depletion rate than did the forested or herbaceous sites. Type of vegetation was apparently of little importance since all vegetated sites depleted at about the same rate. Depletion rates in the winter were similar for all sites save for Headquarters Forested site which shows a much more rapid depletion rate than the rest, possibly as a result of drainage through old root channels.

Taylor, R. E., and Larsen, D.E.

1954 Development of methods for predicting soil moisture content. Office report on the Albuquerque, New Mexico study. 107 pp. plus appendix.

Soil moisture studies were carried out on seven sites at five locations in the vicinity of Albuquerque, New Mexico, during the year starting in April, 1953. Three sites were located at the Pine Flat area on silt loam soils at 7340 ft. altitude, Pinyon, with a cover of pinyon pine and scattered grass, Herbaceous, with a cover of blue grama and other perennial grasses and forbs, and a bare site. One site San Antonito, was located on loam soil at 6750 ft. and had a cover of scattered pinyon pine and juniper with perennial grasses. Another site, East Mesa, at 5160 ft. on fine sandy loam had a scattered cover of Russian thistle and perennial grasses. On a poorly drained silty clay, another site, Flood Plain, at 5000 ft. had a heavy grass (Stipa spp.) and sunflower cover. The last site, Jemez Dam, at 5380 ft. was on fine sandy loam with a sparse cover of grasses and weeds. Bare sites were also established at San Antonito, East Mesa and Flood Plain.

Since precipitation was meager, artificial wetting was necessary to obtain depletion rates. Sheet metal wetting rings six feet in diameter were used for this purpose and each site was wetted twice in summer, fall, and spring. Soil cracking occurred to considerable depth on the bare sites. Here, as at Delta, Rockford, and Miles City, soils at most sites did not reach field maximum moisture content. For this reason depletion curves are calculated from fragments which do not extend to the field maximum. None the less these curves were used successfully in prediction.

Depletion curves for bare sites (using the ring test areas) are more similar than for the herbaceous sites. Most bare sites also show fall and summer curves which are quite similar. Air temperatures were not appreciably different at these particular sites between fall and summer test periods. In general, stations at higher altitudes show lower depletion rates than stations at lower altitudes. Deviations of predicted soil moisture from actual soil moisture averaged 0.056 inch and 0.05 inch for the 0-6 and 6-12 inch depths respectively.

Thames, J. L., Tobiaski, R.A., and Swanson, E. I.

1954 The development of methods for predicting soil moisture content. Office report on the Rhinelander, Wisconsin study. 64 pp. and appendix.

During the year beginning May 1, 1955, soil moisture conditions were studied on fourteen sites in the vicinity of Rhinelander, and two in the vicinity of Ashland, Wisconsin. The sites included a range of soils (in five soil series, Spencer, Ontonagon, Antigo, Vilas and Peat) from sands through sandy loams, and silt loams to clay loams, and peats. On most soil types both forested and herbaceous sites were studied. A daily record was obtained with fiberglas units at three sites. Records obtained gravimetrically at six other sites were compared with the daily fiberglas unit readings. There appeared to be a consistent relationship and on this basis calibration curves were prepared for these six sites and daily records were calculated. These were checked periodically by gravimetric sampling. Gravimetric data were obtained for seven other sites and were used to prepare curves from which daily moisture contents could be estimated. The three peat sites were at or near saturation throughout the period of study.

Since it appeared doubtful that the relationship between moisture content by fiberglas units determined at one site and gravimetric determinations at other sites would hold through the winter season of melting snow, etc., winter data was presented only for sites on which actual data was available.

Generally cool weather and frequent rains resulted in low depletion rates during spring and early summer. Greatest and most rapid moisture losses occurred during July and August. During the fall, soil moisture loss was at a minimum as a result of low soil moisture levels, cool temperatures and curing vegetation. During this period, the average rate of loss at the herbaceous sites was about .011 and .013 inches per day and at the forested sites .007 and .004 inches per day in the 0-6 and 6-12 inch layers, respectively.

Winter depletion rates were used on forested sites until May 10 at which time spring rates were applied. Spring rates were applied on herbaceous sites at the inception of the study, May 1. Summer rates were used on the forested sites from June 6 until September 11, while on the herbaceous sites summer rates started a week earlier. The summer period ended at the same time, September 11, on all sites. A comparison of average depletion rates (table 1) indicates that herbaceous sites deplete at a faster rate than the forested sites during the transition period of spring and fall. This remains true during the summer, although the difference is of lesser magnitude.

Table 1.[6/] Average depletion rate in inches per day for forested and herbaceous sites (Two sites with high water tables have been deleted) at Rhinelander.

Period	Depth Inches	Forested Sites (No. 3,5,10,11)	Herbaceous Sites (No. 2,8,9,12)
Winter	0-6	.022	--
	6-12	.005	--
Transition	0-6	.029	.047
	6-12	.015	.032
Summer	0-6	.079	.082
	6-12	.042	.051

Depletion occurred at markedly lower rates on the herbaceous plots near Ashland as compared to these near Rhinelander (Table 2). (No forested plots were available at Ashland for comparison).

6/ Tables 1, 2, and 3 are based on depletion data for the first 12 to 15 days following maximum moisture content.

Table 2. Average soil moisture depletion rates on herbaceous cover in inches per day.

Period	Layer in inches	Rhinelander Spencer Silt Loam (Site No. 2 and 12)	Ashland Ontonagon Series Clay and Fine Sandy Loam (Site No. 15 and 16)
Transition	0-6	.056	.020
	6-12	.040	.016
Summer	0-6	.087	.055
	6-12	.060	.037

Depletion from the sandy soils is in general higher than from the silt loams during the winter and transition periods. However, during the summer period this is reversed and the silt loams show a more rapid rate of water loss. (Table 3).

Table 3. Comparison of average soil moisture depletion rates on sands and silt loams in inches per day.

Period	Depth Inches	Sandy and Loamy Sand (Vilas series)	Silt loams (Spencer and Antigo Series)
Winter	0-6	.038	.018
	6-12	.004	.004
Transition	0-6	.045	.036
	6-12	.015	.023
Summer	0-6	.063	.075
	6-12	.030	.045

On one of the Vilas silt loam sites a prediction method was developed for the 6-12 inch layer using predicted ground water levels, a record of rainfall and a knowledge of the relationship between the moisture content of the 6-12 inch layer, and the distance between this layer and the water table. Predicted well levels compared favorably with actual well levels, with an average deviation of predicted from actual of .03 of a foot. Average deviation of actual from predicted moisture content of the 6-12 inch layer was 0.1 inch.

Deviations of predicted moisture content from actual moisture content by the standard method fell between 0.04 and 0.18 inches for the 0-6 inch layer and between 0.01 and 0.14 inches for the 6-12 inch layer at all but one site.

[illegible], R. A., and [illegible], W. E.

1956 The Development of Methods for Predicting Soil Moisture Content. Report on the Fairbanks, Alaska Locality, Corps of Engineers, U. S. Army, Waterways Experiment Station Miscellaneous Paper Number 4-135, 68 Pages and Appendix.

Seventeen sites were established in the vicinity of Fairbanks, Alaska for the study period May through September 1954. Only twelve sites were suitable for use since on five sites perma-frost occurred near the surface throughout the period of observation. This resulted in a stabilized water table with small variation in the water content of the 0-12 inch layer. Sites were underlain by loess, alluvium, peat, and mixtures of these materials. Surface drainage varied from good to poor and vegetation from grasses, sedges, and forbs through brush to aspen, birch, and spruce forest in various mixtures.

Depletion in the 0-6 inch depth showed a fairly uniform rate of .03 - .06 inches per day for the first ten days after field maximum soil moisture. This was true without regard to vegetation type save on steeper slopes with southern aspects where the forested sites had an accelerated drying rate. On a 32 degree slope a forested site depleted at a rate of 0.146 inches per day while a herbaceous site depleted at a rate of only 0.05 inches. This may in part be a result of lower maximum moisture content on the herbaceous site as well as of the lighter herbaceous cover.

Difference in slope and aspect did not appear to influence depletion at the 6-12 inch depth, but the type of vegetation did have an effect. Forested sites tend to deplete at an average rate of 0.05 inches per day while herbaceous sites had an average rate of 0.02 inches per day. Here again the field maximum is somewhat lower on the herbaceous sites.

Predictions of soil moisture content were made for ten sites with an average deviation of predicted from actual moisture content of 0.06 inches in the 0-6 inch layer and 0.05 inches in the 6-12 inch layer. Predictions were carried from the latter part of May through September. For most sites the spring to summer transition date used was June 1, while the summer to fall date fell about September 15.

Soil strength data were obtained at all sites save those with perma-frost and a significant linear relationship was found between soil strength and soil moisture for seven sites investigated. (Four sites at the 1% level and three sites at the 5% level).

PART III

SPECIAL STUDIES

Equipment and Techniques for Measurement of Soil Moisture

Since the purpose of the Vicksburg Research Center has been the prediction of soil moisture, most of the field work of the center has been concerned with the measurement of soil moisture and related factors. The following general conclusions are drawn from this work and are discussed in more detail in the papers referenced.

Electrical Soil-Moisture Measurement

Fiberglas soil-moisture units have been used throughout most of the Vicksburg work. They are durable in the soil, having been in service in some areas for more than three years. Their small size allows insertion into the soil with a minimum of disturbance. The built-in thermistor permits accurate adjustment of resistance readings to a constant temperature level. The units can be read rapidly and the readings converted to percent soil moisture with a minimum of effort (Norton, 1955; Lull and Reinhart, 1955; Palpant and Lull, 1953).

Both soil pits and 5 inch auger holes were tested for installation of soil moisture units. Experience indicated that the auger hole installation was superior to the pit. It requires less labor to dig and results in far less disturbance to the site; an important factor both in getting accurate readings and in preserving space for gravimetric sampling necessary for calibration of the units (Reinhart, 1953). The auger holes should be refilled carefully, with soil in a slightly moist condition, by layers arranged in their original sequence and packed to the original density.

The choice of the auger hole type of installation for several series of soil moisture units stimulated the development of a device for installation of these units in the wall of the hole without disturbance to the soil. An instrument was devised using the principle of the scissors-type auto jack. The unit is placed in the inserter and the instrument lowered into the soil. Then with a few turns on the handle the unit is pushed into the soil. The handle is then turned back and the inserter is removed (Palpant, 1953).

In order to read a large number of units on a daily basis a variety of devices were developed and tested. The first was a waterproof switching device to which many units were connected; (Palpant, Thames and Gilmore 1953) later a portable switch was devised which was carried with the moisture meter; finally, stationary terminal boards were used to which the meter could be attached by battery clamps (Doss and Broadfoot, 1954).1/ The terminal boards are simple in construction, not subject to damage by dampness, and proved most satisfactory.

1/ Phone-jack terminals have also been used for this purpose. See Woods, F. and Hopkins, W., 1954. Phone-jack terminals for soil-moisture units. Southern Forest Experiment Station Occasional Paper 135, Pages 32-33.

Field calibration has been the practice in all Vicksburg studies (Carlson, 1954; Reinhart, 1950). Care is necessary to protect the site from disturbance. King tube probes provide adequate samples with little disturbance. Field calibration must be timed carefully to get the full moisture range. Some variation is to be expected even over a small area and sampling in duplicate at random on a prearranged sample plan has been the practice. Field calibration also has the advantage of giving average moisture for an area rather than at a point. Average moistures for a soil, rather than point values, were desired.

Nuclear Instruments

A nuclear instrument for measurement of soil moisture and density was tested but not adopted. When tested this method proved too slow in operation for making numerous measurements, did not measure sufficiently narrow layers, was not sufficiently reliable and finally was too expensive for general use. With improvement and simplification it may become valuable since it measures density as well as moisture content (Bush and Reinhart, 1955).

Soil Bulk Density

Soil bulk density measurement was a difficult and important phase of the soil moisture study. Bulk density seemingly varied with the moisture content of the soil. It was subsequently found that bulk density varied from point to point, and moisture varied correspondingly. The relationship between moisture and density was one of association rather than cause and effect. Moisture did not cause low bulk density (through swelling), but high moisture is associated with low bulk density. In addition, ease of extraction of the test core varies with the organic matter, texture, structure, and moisture condition of the soil. The resultant reliability of the bulk density measurement will vary with the condition of the core. The problem lies in finding a core sampler or perhaps a set of samplers that can be used over the range of soil conditions. Such tools have not yet been devised.

The modified San Dimas sampler has been the most generally acceptable method used at Vicksburg. Core samples with this tool can be used directly for bulk density determinations, or can be used with the air piezometer (Broadfoot, 1954).

At Vicksburg soil moisture determinations are expressed in inches of water per six inches of soil depth. Soil moisture is determined by the formula:

$$d = \frac{(M)\ (B)(D)}{100}$$ where (d) is the moisture content in inches, (M) is the moisture in percent of dry weight, (B) is the bulk density, and (D) is the thickness of the soil. It can be shown that the product of variable bulk density times variable volume, or thickness of a soil mass remains constant and independent of moisture content. Thus, though a change in moisture content may really change the volume occupied by a given soil mass, the change does not affect inches of water determinations by electrical resistance methods.

Ninety regressions of moisture on bulk density for various soils around Vicksburg showed significance in only 28 per cent of the regressions. However, soil weight per unit volume is a common element in both variables, and there is a correlation between moisture constant at a given tension and amount of pore space independent of shrinking and swelling (Reinhart, 1954). The influence of moisture content on bulk density of these soils may be small enough to be negligible on the particular soils tested (loess silt loams and water deposited clays).

Moisture Tension Analyses

In laboratory determinations of soil moisture-tension relationships, it was found that:

1. At tensions below one atmosphere, field cores of natural structure should be used as they retain less water.

2. At tensions above one atmosphere either field cores or bulk samples give equivalent results (Broadfoot, 1954).

Broadfoot, W.M.

1954 Procedures and Equipment for Determining Soil Bulk Density, Occasional Paper 135, Southern Forest Experiment Station, Pages 2-11.

The "block", San Dimas, and air picnometer methods were used to determine bulk density on 180 samples of Mississippi alluvium and loess.

In the "block" method, a block of soil 12 inches square by 3 inches in depth was used. The San Dimas sampler takes a cylindrical core of 288 cubic centimeters. The air picnometer measures volume of air per volume of soil in a cylindrical sample. With the weight of the core, known conversions were made to moisture content and bulk density from nomographs.

The following table, from the article, gives a comparison of these methods (1 designates best; 3 poorest):

Rating Factor	Block	San Dimas	Air Picnometer
Disturbance of the Sampling Area	3	1	3
Compression or Disturbance of the Soil Sample	1	3	2
Personal Skill Required	3	1	2
Utility in Dry Soil	3	3	1
Time Required	3	2	1

The block method gave lower bulk densities than the other two methods, and the San Dimas slightly higher than the air picnometer. However, block samples could be taken only when the soil was moist, and were thus probably biased in results.

Broadfoot, W.M.

1954 Cores vs Samples in Soil-Moisture Tension Analysis, Southern Forest Experiment Station Occasional Paper 135, Pages 22-25.

Comparisons were made between the use of cores and of bulk samples for the determination of moisture contents at various tensions up to 15 atmospheres.

"In soil moisture tension analysis some soil had higher moisture contents at 1/3 atmosphere tension than at 60 cm. of water (.06 atmosphere). This was noted particularly in fine-textured soils, and was thought to be related to the difference in relative disturbance of the soil samples used under the two tensions. Accordingly, a comparison was

ences in the moisture contents of core and bulk samples at various tensions:

"Moisture contents of the bulk samples at 5 cm. of water (.005 atmosphere tension) were significantly higher than those of the core samples, ranging from 34 percentage points higher for the Commerce silty clay to 10 points higher in the very fine sandy loam soil. As tension was increased to 60 cm. (.06 atmosphere) the difference decreased but was still significantly higher. The difference in the means remained significant throughout the intermediate tension range of .1 to 1 atmosphere, except for the very fine sandy loam. For the sandy soil, bulk samples were significantly higher in moisture content only up to .1 atmosphere tension."

"At 3 and 15 atmospheres, it was only in the Commerce silty clay that bulk samples had significantly higher moisture contents than the cores. At the same high tensions, cores of the very fine sandy loam and the silt loam from Missouri tended to have slightly higher moisture contents than the corresponding bulk samples. Differences, however, were not significant."

Carlson, Charles A.

1953 Moisture Equilibration in Natural Cores During Laboratory Calibration of Fiberglas Soil-Moisture Units, Southern Forest Experiment Station Occasional Paper 128, Pages 31-39.

Electrical resistance units were placed in three soils at varying depths. These units were then removed in "natural" cores consisting of cylinders 2.58 inches in diameter, and 2 and 3 inches long. These "natural" cores were then taken to the laboratory for soil moisture unit calibration.

It was found that 95% saturated lead nitrate solution actually dried the cores rather than equilibrating them. It was concluded that for equilibration treatment a saturated atmosphere is preferred.

Surface evaporation was found to dry cores and create a gradient across them that could not be eliminated by equilibration. Vapor equilibration did not take place overnight in the humid chamber. The experiment showed less moisture gradient in two inch cores than in three inch cores, indicating that shorter cores are best.

Laboratory calibration was not found to be accurate enough to replace field calibration for fine soils in a humid climate. Laboratory calibration was used only to check the general shape and range of the field curves, and was done by continuous air drying with periodic measurements of core weight and unit resistance.

Carlson, Charles A.

1954 Comparison of Laboratory and Field Calibration of Fiberglas Moisture Units, Southern Forest Experiment Station Occasional Paper 135, Pages 34-42.

Termination of certain field studies with fiberglas moisture units provided an opportunity for a comparison of field and laboratory calibration. Identical units were used in the same soils in which they had been calibrated in the field. Calibration curves are presented for three cycles

drying and one of wetting in the laboratory and the possible causes of differences are discussed.

Generally the laboratory curves were drier than the field curves at a resistance of fifty kilohms, and wetter at a resistance of 0.5 kilohms. Successive drying cycles showed, generally, the first drying curve to be closer to the field curve than the other two.

Laboratory curves tended to be moister than field curves with increase in depth. The reason was thought to be that at lower depths in the field diffusion is restricted and the carbon dioxide level increases, thus bringing more salts into solution and consequently lowering resistance at given moisture contents. Swelling was thought to be a possible factor, but binding samples with wire had no measurable effect on moisture-resistance relations.

Moisture gradients within the core caused error at high resistances. Ends of cores were drier than the centers, giving the drier laboratory curve at high resistances.

Variation was also attributed to the fact that field curves were a combination of wetting and drying periods, and the laboratory curves were predominantly drying curves.

Carlson, Charles A.

1954 A Core Method for Determining the Amount and Extent of Small Roots, Southern Forest Experiment Station Occasional Paper 135, Pages 43-47.

The method described in this report follows essentially the following steps:

1. Collect the soil sample, a core of known volume.

2. Disperse the roots by soaking the sample about three days in a 0.02 normal sodium hydroxide and 0.005 N sodium oxalate solution.

3. Dilute the soil-root-suspension and wash through a 100 mesh screen to remove the finer soil fraction.

4. Skim off the floating debris from the suspension.

5. Decant the fine roots.

6. Determine the fresh weight and dry at 65 degrees C. to determine the dry weight.

7. Ash the sample to determine the correction for adhering soil particles.

8. Calculate the average diameter, total surface area, and aggregate length of roots for various methods of expression of results.

Doss, B.D., and Broadfoot, W.M.

1954 Terminal Panel for Electrical Soil-Moisture Instruments, Southern Forest Experiment Station Occasional Paper 135, Pages 30-31.

A sturdy weather-resistant terminal panel for a series of soil-moisture units is described. Leads from moisture units are connected with brass screws used as terminals on a plexiglas panel. The meter is connected to the terminals with battery clamps.

Horton, J.S.

1955 Use of Electrical Soil-Moisture Units in Mountain Soils Proceedings 23rd Annual Meeting, Western Snow Conference, Portland, Oregon, Pages 20-26.

The fiberglas soil moisture unit is suggested as a highly satisfactory method of measuring soil moisture in mountain soils. Standard methods of laboratory calibration and field calibration are compared and a system of mass calibration of many units in a single pan is described as an aid in the detection of unreliable units in the laboratory before installation.

"In stony soils, such as are commonly found in the western mountains, calibration of the units by conventional methods is unsatisfactory, both because of variability of the soils and because of the physical difficulty of moisture sampling. Calibration of units installed in very deep soil layers also present a problem in moisture sampling..."

"It has been reasoned that the readings of the units could be used to indicate the trend of soil moisture change without an attempt to determine accurately the actual moisture content. To do this, a wet and a dry field value must be estimated. This can be approximated from the dial readings but it would be better to have laboratory tension values. To estimate the high value it is best to select readings two to three days after the rains are over. These readings approximate field capacity. At the dry end of the curve, wilting point can be approximated by taking the value at the point where the curve flattens out and the readings become constant. The simplest method of determining the trend would be to prorate the intermediate values between these two points on a straight line relationship. To check this method, a straight line was drawn between the wilting point and the field capacity values on calibration curves of twenty fiberglas units installed in the San Dimas lysimeters. The average deviation from the calibration curve was 2.1% soil moisture. This was the equivalent of 0.36 inches of water per foot of soil. Using an arbitrary line curved near the field capacity point would have greatly improved the relationship. This method should be attempted only for well-drained and well-vegetated sites where soil moisture would be lowered to wilting point by transpiration losses."

Conversion of the readings from the dials of the chenter to ohms resistance (or log of ohms resistance) and correction to a constant temperature is normally accomplished using a series of tables. A simplified

[illegible] [illegible] values directly related to soil-moisture percent and eliminate additional conversion.

Lull, H.W., and Reinhart, K.G.

1955 Soil Moisture Measurement, Southern Forest Experiment Station Occasional Paper 140, Pages 1-56

This is a collection of abstracts in which are discussed in chronological sequence the development of methods used in soil moisture measurement. Four types of methods are discussed in some detail: (1) gravimetric methods, (2) electrical resistance methods, (3) the tensiometer method, and (4) the nuclear method.

In resume the authors state that, "As a general rule the gravimetric method should be used unless measurement by one of the indirect methods is absolutely necessary to satisfy study requirements. It requires less experience than any of the others. As it provides direct measurements, the time, the effort, and possibility of error associated with converting resistances, tension measurements, or neutron counts to soil-moisture content are avoided. Even if one of the other methods is chosen, numerous gravimetric samplings are usually required for calibration or checking."

"Electrical-resistance instruments are most useful for securing daily records of considerable duration." Tensiometers appear to be most useful in irrigation studies.

Palpant, E.H.

1953 An Inserter for Fiberglas Soil-Moisture Units, Southern Forest Experiment Station Occasional Paper 128, Pages 19-21.

To obviate some of the disturbance of the soil in inserting electrical resistance units, an inserter was devised for use in the Vicksburg Infiltration Project. The device had to be such that it could be lowered into a 4-3/8 inch diameter hole for insertion of the resistance unit. The device built was on the same principle as the scissors-type auto jack. Modification of the holder for nylon resistance blocks can be accomplished.

Palpant, E.H., and Lull, H.W.

1953 Comparison of Four Types of Electrical Resistance Instruments for Measuring Soil Moisture, Southeastern Forest Experiment Station Occasional Paper 128, Pages 2-15.

Performance of nylon, plaster of paris, fiberglas, and plaster of paris-fiberglas resistance units was described for both field and laboratory observations.

The tests indicated that performance of the units is acceptable through the range of saturation, with the exception of the plaster of paris units which did not respond satisfactorily above field capacity.

Where the accuracy of moisture readings needs to be high, the authors feel that the fiberglas units are desirable. Temperature readings can be taken along with the resistance readings. The necessity of correcting soil moisture readings for temperature was found to be small at high moisture levels. At low moisture levels a considerable correction may be necessary.

Gypsum blocks were found to be too large to be easily pushed into the side of an auger hole and still retain good contact between the soil and the block. The fiberglas and nylon blocks, however, could be easily inserted.

The authors state "Where large numbers of units are read daily, the meter designed for the fiberglas unit is preferable".

Palpant, E.H., Thames, J.L., and Helmers, A.E.

1953 Switch Shelters for use with Soil Moisture Units, Southern Forest Experiment Station Occasional Paper 128, Pages 21-30.

Details for the construction and use of two switch shelters, and a portable switch are given in this paper. They were used in conjunction with the fiberglas soil-moisture units.

At the Vicksburg Infiltration Project, moisture units were used in stacks of eight to ten. To facilitate daily readings, these groups were wired to a multipole selector switch.

A wooden shelter was used to house the switch above ground. Where snowfall or rains are heavy, or where the switch must be placed below ground, a waterproof installation, such as the plexiglas housing is desirable.

The authors conclude, "On large installations of many stacks, the portable switch with a sturdy plug would prove the cheapest and simplest to install once the switching unit has been constructed".

Reinhart, K.G.

1953 Installation and Field Calibration of Fiberglas Soil-Moisture Units, Southern Forest Experiment Station Occasional Paper 128, Pages 40-48.

Installation of units in auger holes is preferable to pits because of less disturbance to the site. Installation should be made, if possible, when the soil is moist so that the hole may be repacked successfully. The units are placed perpendicular to the ground surface. The wires are led downward before being brought to the surface in order to prevent water movement along the wires to the units.

The site must be carefully protected from disturbance. Wooden platforms, well marked paths, and several feet of cable to the unit lead wires help to prevent trampling. Fencing will keep out animals.

The reading of the fiberglas unit may be used to represent moisture

content at a point, or over an area. The area concept is more useful, and is more in keeping with the method of field calibration.

"Under the area concept the unit is installed in or adjacent to the area it is to represent -- at Vicksburg usually a plot 6 by 6 feet square. It is calibrated by drawing soil samples at random from this area and plotting the moisture contents of the samples against the resistance determined at the time the samples are taken. The resistance is an index of average soil moisture at a particular soil depth over the entire sample plot. This is a distinct advantage, because the marked deviation in soil moisture that occurs even within a small area gives the value for a single point little significance."

Reinhart, K.G.

1954 Relation of Soil Bulk Density to Moisture Content as it Affects Soil Moisture Records, Southern Forest Experiment Station Occasional Paper 135, Pages 12-21.

In many soils studies it is necessary to convert moisture content in percent to inches depth of water. This paper points out some of the difficulties involved.

In this regard, the taking of good bulk density samples is a source of trouble. Texture, structure, organic matter, and shrinking and swelling with changes in water content, all influence bulk density.

Of 90 regressions of moisture content on bulk density, 28 indicated a statistically significant relationship, and 66 showed decreasing bulk density with increasing moisture content. However, the author says, "...these regressions are affected by the fact that soil weight per unit volume is a common element in both variables, and by the correlation between moisture content at a given tension and amount of pore space independent of soil shrinking or swelling. It is believed that the effect of moisture content on bulk density of these soils is small enough to be disregarded with respect to gravimetric sampling".

The author concludes "...that even with gravimetric sampling it is unwise to attempt to adjust bulk density for variation in moisture content (especially percent by weight) because bulk densities determined under dry conditions are likely to be inaccurate and because such inverse relationships as have been found are due only in part to shrinking and swelling of soil".

Rush, E.S., and Reinhart, K.G.

1955 Field Tests of Nuclear Instruments for the Measurement of Soil Moisture and Density, Waterways Experiment Station, U.S. Army, Corps of Engineers, Miscellaneous Paper 3-117, Pages 1-26.

The results of field tests with nuclear instruments designed for the determination of soil moisture and soil strength are reported in detail. Moisture measurement by this method requires a source of fast

neutrons which are slowed down or deflected by the moisture in the soil. Density determination requires a source of gamma radiation which is deflected or suffers loss of energy depending upon the soil density.

Equipment includes a source of fast neutrons, (Radium D - Beryllium), a source of gamma rays (Cobalt 60), separate probes; one for moisture readings and the other for density readings, a scaling device and timer, access tubes, standards for moisture (water) and density (concrete), and a portable generator.

The authors say, "For users requiring measurements less frequent than in the Forest Service studies referred to", (up to 200 moisture readings a day) "the time savings resulting from application of one calibration curve for general use (as compared to individual calibration of electrical-resistance units) may more than offset the additional time required for individual moisture measurements". That is, the nuclear device used required one curve for all depths while electrical units need to be calibrated individually.

Physical Properties of Soils

During the period from June 1954 to July 1955, soil samples were collected and analyzed from 614 sites in the South, Northeast, North Central, and Intermountain areas of the United States. Prior to this time the characteristics of 14 Mississippi soils had been examined. The data on soil properties may be of interest to soil scientists. Standard methods were used throughout for both field and laboratory procedures and are described briefly.

The data obtained for each soil series was as follows:

1. Description of Vegetation and Land Use.
2. Topographic Position and Slope.
3. Textural Class.
4. Mechanical Analyses (by percent by weight)
5. Organic Matter (by percent by weight)
6. Plasticity Constants (liquid limit, plastic limit and plasticity index).
7. Bulk Density (grams per cc.).
8. Soil Moisture (at saturation and at 0.06 atm. tension).
9. Stone Content (percent by volume).

Doss, B. D., and Broadfoot, W.M.

1956 Properties of 91 Southern Soil Series, Southern Forest Experiment Station Occasional Paper 147, 15 Pages and 7 Tables.

These 91 soil series were selected as typical of the soils of the Gulf Coastal Plain and the lower Mississippi Valley.

Eschner, A.R., Jones, B.O., and Moyle, R.C.

1957 Physical Properties of 134 Soils in Six Northeastern States, Northeastern Forest Experiment Station Paper 89, 10 Pages and 11 Tables.

The 79 series were considered to be typical of the podzolic soils of the Appalachian Plateau Province in Pennsylvania and New York and the southern portion of the New England Maritime Province.

In addition, this paper presents relationships between bulk density and soil texture and organic matter content, which may be summarized as follows:

"The overwhelming importance of organic matter - and, by inference, management practices - in reducing the bulk density and thus increasing the total moisture-holding capacity of the soil was demonstrated. Soil texture has a less important role in determining bulk density."

"Probably the most important effect of texture in the surface soil is its influence upon organic-matter accumulation. The significant correlation of clay and organic-matter contents agrees with general observations that organic-matter accumulation is favored in finer-textured soils. This relationship does not appear to hold for the 6 - 12 inch depth. There, the direct effect of texture on bulk density becomes more apparent."

Taylor, Robert E.

1956 Some Properties of 144 Soils from Three Intermountain States, Intermountain Forest and Range Experiment Station Miscellaneous Publication Number 7, 6 Pages and 4 Tables.

The area covered included southern Idaho, Utah, and the eastern edge of Nevada.

Fifty-three soil series are listed. Soils were identified whenever possible from United States Department of Agriculture descriptions.

"Soil survey maps and descriptions which were of valuable assistance in identification were supplied by both the Utah and Idaho Soil Surveys. In spite of these efforts, 45 soils could not be identified as to series

and are designated as desert, desert playa, alluvial bottom, mountain valley, or mountain soils in the tables. Nearly all the unidentified soils were in areas that had not been surveyed, though a number were in surveyed areas where they could not be correlated with known series."

Thames, John L., and Swensen, Edmond I.

1956 Properties of 160 Soils of Four North Central States, Lake States Forest Experiment Station Paper Number 138, 6 Pages and 5 Tables.

Sixty-five soil series were listed. Twenty-one soils were not classified.

The soil series sampled were considered to be typical of the soils in the prairie and glaciated regions of this portion of the Midwest. The states covered included northern Illinois, Iowa, Minnesota and Wisconsin.

Broadfoot, W.M. and Raney, W.A.

1954 Properties Affecting Water Relations and Management of 14 Mississippi Soils, Mississippi State College Agricultural Experiment Station Bulletin 521, 18 Pages.

The fourteen soils described represent the principal soils of Mississippi. In this study characteristics of the soil profile are described for all 14 soils. Infiltration rates were determined for ten of them.

<u>Soil Moisture Relations</u>

The studies in soil moisture prediction were discussed at length in Part I. This material, however, is not available for general use.

Papers listed here treat specific phases of the work on soil moisture and have been published in journals which are readily available. The subjects covered include moisture in the forest floor, field maximum moisture content, a summary of the prediction method, an annotated bibliography on evapotranspiration, a discussion of the available water storage in the soil in relation to infiltration, and a consideration of the soil moisture regime in forest and non-forest soils.

Broadfoot, W. M.

1953. Moisture in Hardwood Forest Floor, Southern Forestry Notes Number 85, U. S. Forest Service, Pages 3-4.

"In the moisture studies at Vicksburg, Mississippi during the summer of 1952, it was found that a hardwood forest floor (organic debris down to mineral soil) of 1 inch average depth would lose, within 5 days following light showers, 96 percent of its field moisture. The storage capacity of the hardwood floor was 0.12 inch of water."

"The first day following rain of approximately 0.2 inch (measured underneath the forest canopy) the moisture content of the forest floor amounted to 50 percent of the storage capacity, and on successive days, until the 5th day, the moisture was 25, 10,6,and 3percent of storage capacity, respectively. At no time during the unusually dry summer did the moisture content go above 50 percent of storage capacity. However, it could reasonably be assumed that the moisture content would reach 90 to 100 percent of storage capacity, or about 0.1 inch moisture, under winter conditions of frequent rainfall and low evaporation losses."

"The change in forest-floor moisture content following precipitation was affected somewhat by the length of time the forest floor had been dry. For example, a 0.1 inch shower following a dry period of 2 weeks or longer would add water equivalent to only 12 percent of the storage capacity, whereas a similar shower following a previous shower by 5 days would add moisture equal to 45 percent of the storage capacity."

Carlson, Charles A., and Pierce, R. S.

1955 The Field Maximum Moisture Content. Soil Sci. Soc. of Amer. Proc. 19(1): 81-83.

"The field maximum moisture content is defined as the naturally occurring wet limit of a soil or soil layer in its natural position. Values were obtained by selecting recurring peak values from daily records of soil-moisture content. For most soils the values tended to coincide with the 0.06 atmosphere soil-moisture tension values of core samples. In poorly drained soils the field maximum approached the total pore volume. The field maximum helps characterize the full range of naturally occurring soil-moisture content."

Carlson, Charles A., Reinhart, K.G., and Horton J.S.

1956 Predicting Moisture in the Surface Foot of Soil. Soil Sci. Soc. of Amer. Proc. 20(3): 412-415.

"A method of predicting moisture content in the surface foot of soil has been developed by the U. S. Forest Service in cooperation with Corps of Engineers, U.S. Army. By this method moisture can be predicted for a given soil from the wettest to the driest conditon that

naturally occurs. In development of the method, soil wetting and drying relations were determined from detailed soil moisture and concurrent weather records. Wetting in the surface foot was found to depend primarily on the amount of rainfall and the amount of space available for storing water. Drying varied with the moisture level of the soil; it followed the characteristic curve for each season. Information needed for prediction - in addition to the wetting and drying relationship - includes the field maximum moisture content, transition dates for the seasonal depletion curves, and the size of the smallest storm which affects soil moisture. Records on prediction relations are being obtained for 146 experimental sites throughout the United States, Alaska, and Puerto Rico."

Lull, Howard W.

1953 Evapo-Transpiration: Excerpts from Selected References, Southern Forest Experiment Station Occasional Paper 131, 117 Pages.

This publication contained 76 abstracts from selected references under the following subject headings:

General Discussion; Evaporation; Transpiration; Roots and Soil Moisture; and Roots.

"From the more recent research, one conclusion stands out which is as important as it is simple: During the growing season, rates of evapotranspiration are governed first by the availability of water supplies. When and where supplies are ample, rates are controlled by atmospheric factors, the nature of vegetation, or both acting together. Where supplies are limited, the rates of loss are principally a function of the amount of available soil moisture. To this must be added the observation that, country-wide, supplies are for the most part limiting."

Moyle, R.C. and Zahner, R.

1954 Soil Moisture as Affected by Stand Conditions, Southern Forest Experiment Station Occasional Paper 137, 14 Pages.

Soil Moisture depletion was measured under six different forest conditions in southern Arkansas. Available moisture was measured at 4 depths (0-6, 6-12, 20-26, and 42-48 inches). Three of the sites had been treated to remove some or all of the vegetation and the other three had been left forested.

The authors state: "Where pine or hardwood stands with a stocking of 70 to 100 square feet of basal area were undisturbed, water was removed from the ground rapidly with the onset of hot, dry weather. On plots where large cull hardwoods were deadened, and where all living vegetation was removed, soil water remained relatively high throughout the summer."

Summer rainfall was light and moisture added to the ground was quickly lost by evapotranspiration.

"Soil water depletion was greater where all vegetation had been removed than where only the culls had been deadened, but this difference was apparent only in the surface layers, (0-18 inches). Below the effective zone of evaporation on these sites, soil water remained at a rather constant high level."

The authors conclude that serious consideration should be given to stand treatments which might conserve moisture for more desirable species. They point out that the summer drought is almost a yearly event in the western part of the shortleaf-loblolly pine-hardwood type.

Reinhart, K. G., and Taylor, R.E.

1954 Infiltration and Available Water Capacity in the Soil. Trans. Amer. Geophys. Union 35(5): 791-795.

"Antecedent soil-moisture content has long been recognized as one of the important factors affecting infiltration rates of most soils." A study on an upland silt loam site, and a low-land silt loam site on the east bluff of the Mississippi River shed some light on the inter-relationship between infiltration rates, soil moisture content, and available storage.

It was found that the amount of infiltration into a soil column of a given depth was equivalent to the amount of water percolating through the column, and also the amount retained within the column, the latter being limited by the available storage.

In this study it appeared that regardless of the antecedent moisture conditions infiltration at a given site tended to level off at the same value. The greater the antecedent storage, the longer it took to reach this level.

In applying artificial rainfall at intervals of 1, 2, and 4 hours, the authors found the infiltration rate after the drying period apparently exceeded that before the break for the first 10 minutes, however, the recovery of available storage after completion of the runs was quite low.

Rainfall records and moisture contents in the soil before and after storms were evaluated to see if the rainfall rate exceeded the infiltration rate. Lateral flow from adjacent areas caused soil moisture levels to be higher than could be accounted for by the rainfall and prevented the making of a valid comparison.

The authors conclude, "These tests were exploratory. They demonstrate the possibilities of using soil-moisture records rather than proving their worth. This approach is feasible only when the soil moisture records include the full depth of moisture penetration. For soils studied, the relationship between amount of accretion and amount of infiltration is generally good..."

Thames, John L., Stoeckeler, Joseph H., and Tobiaski, Robert

1955 Soil Moisture Regime in Some Forest and Non-Forest Sites in Northern Wisconsin. Soil Sci. Soc. Amer. Proc. 19(3): 381-384.

A forested site and a "timothy hay" site both on Spencer silt loams were compared. In the surface one to two feet, the forested site had less total water and less available water than the "timothy hay" site during the middle and late summer. Heavy depletion by the root zone of the forested site, a thick layer of leaves, duff, and humus, and interception of precipitation by foliage were believed to be the reasons. The "timothy hay" site had bulk densities 25 and 32 percent greater in the surface foot and two feet respectively.

Two forested sites on sands were compared. One had a water table at 2.0 feet from the surface, and the other at 4.5 feet. During most of the growing season, the high water table site had 0.4 inches more water in the surface foot, or about 4 percent more by volume in the surface 2 feet. More capillary water in the high water table site is believed to be the reason for the greater moisture in the upper two feet. The low water table site was predominantly jack pine and aspen, while the high water table site had been invaded by black spruce and tamarack. During the dry portion of the growing season the water table dropped 1.3 feet on the high water table site, and 1.5 feet on the other.

SUPPLEMENT

This supplement contains selections from the Vicksburg work that have been completed since 1957 or are now in process of being published.

Bassett, J.R., Rush, E.S., Brennan, R.I., Tobiaski, R.A. and Anders,[illegible]

1959 The development of methods for predicting soil-moisture content and soil strength: Report on the Puerto Rico Extension. Forest Service, U.S.D.A. and U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss. Technical Report (Being reproduced by Army Engineers).

Data collected from May 1955 to June 1956 at 30 sites in Puerto Rico were used to develop a method to predict soil-moisture content and soil strength in the 0- to 6-in. and 6- to 12-in. layers of soil. The prediction method which had been found applicable to sites in the continental United States and Alaska was applicable to Puerto Rican sites also.

Average prediction relations derived from 8 prediction development sites for the 6- to 12-in. layer yielded predictions of soil-moisture content which varied from those actually measured within the order of 0.3 in. water per 6-in. of soil, or 3.6%, when used in the prediction method and applied to the 8 prediction development and 22 survey sites in Puerto Rico. However, prediction at some individual sites was of a much lower order of accuracy.

Average prediction relations derived from several prediction development sites located in drier climates of the continental United States yielded less accurate (0.39 in. water in the 6- to 12-in. layer, equivalent to 4.6% soil moisture content) predictions of soil-moisture content when used in the prediction method and applied to the 30 prediction development and survey sites located on wet areas of Puerto Rico. These prediction relations were unsatisfactory principally because their average depletion curves, based on United States data, were considerably different in shape from the average depletion curves based on Puerto Rican data.

Soils at Puerto Rican prediction development sites remained comparatively wetter throughout the year than soils at prediction development sites in the Unites States.

The yearlong average daily rate of soil-moisture loss in the 0- to 12-in. layer of soil in Puerto Rico slightly exceeded one half the average summer rate and about equaled the spring-fall rate in humid climates of the United States, including Alaska. Soil-moisture depletion rates in Puerto Rico did not seem to be affected by season.

The relatively low rate of soil moisture depletion in tropical wet areas of Puerto Rico, as compared to drier climates in temperate zones, appeared to be due to the accumulation of the effects of physiological processes or environmental factors such as high and frequent rainfall, microclimatic "vapor blanket", shorter summer days, lower maximum summer temperatures, and the weaker caloric effect of the tropical sun.

Cone index-moisture content comparisons correlated fairly well, with an average deviation of 18 cone-index units for the range of moisture encountered; average minimum cone index for the prediction development sites was 203. Rating cone index-moisture content comparisons correlated fairly well, with an average deviation of 21 rating-cone-index units for the range of moisture encountered; average minimum rating cone index for prediction development sites with soil-strength data was 166, and the range of minimum rating cone indexes was from 109 to 234. Remolding index-moisture content correlations were poor; the range in remolding index was from 0.74 to 1.08.

On the basis of rating cone indexes, the trafficability of the Puerto Rican sites tested was generally good.

Analysis of moisture content and cone index, rating cone index, and remolding index for the 8 prediction development sites revealed the following average deviations: cone index, 18; rating cone index, 21; remolding index, 0.05.

Broadfoot, W. M. and Burke, H. D.

1958 Soil-Moisture Constants and Their Variation. U.S.D.A. Forest Service, Southern Forest Experiment Station, Occassional Paper 166.

This paper is an accumulation of average values, on soil moisture constants, from literature and Vicksburg research. The average soil moisture content of the U.S.D.A. soil textures is given for some soil moisture constants: field capacity, wilting point, tension values, field maximum, field minimum, moisture equivalent and others. A discussion of the soil moisture constants in relation to land use is presented. A means of estimating bulk density of soil from soil properties is also included.

Burke, H. D. and Krumbach, A. W., Jr.

1959 Nitrogen Probe for Soil Moisture Sampling. In process of publication by Journal of Geophysical Research.

Moisture determinations were made on soil samples frozen to hollow probes into which liquid nitrogen (boiling point -320.4° F.) had been poured. Samples were obtained over a range of soil moisture by weight from 4 to over 120 percent. Values compared closely with those using more conventional methods. This procedure was developed to obtain soil samples containing free water. It may be useful for obtaining samples of soft sediments and for calibrating indirect methods of soil moisture measurement through the full range of soil moisture.

Burke, H. D. and Turnbull, W. J.

1959 Prediction of Soil Moisture from Soil and Weather Records. Paper to be presented at Symposia on Forest and Water and Lysimeters. International Geophysical Union, Hannover-Munden, Germany. September 1959.

This paper presents the basic processes of soil moisture prediction and briefly discusses soil moisture accretion and depletion, field maximum and minimum moisture contents and the application and testing of the method in the United States.

Krumbach, A.W., Jr.

1959. Sampling Intensity for Determining Horizontal and Vertical Variation of Soil Physical Properties on a Loessial Bottom Soil near Vicksburg, Miss. A report in progress.

Prediction accuracy for soil moisture and strength is governed by the accuracy to which the factors used in the prediction system can be measured. There is, then, no point in trying to refine the prediction system more closely than the factors which go into the system can be measured. Soil physical properties constitute a major portion of these factors.

In a particular soil, the absolute value of a soil property varies from point to point, and from depth to depth. Proper characterization of this variation determines the accuracy to which the property is measured.

In sampling, the number and spacing of observations determines how well variability is measured, and ultimately, the accuracy of the estimate of the property in question.

Conceivably moisture-strength might have to be predicted for any soil in the world. So, it was decided to undertake a program to characterize variability of soil physical properties for each genetic group of soils, and to begin this program by intensive studies on a soil within the group, which would be as variable as any encountered.

Loessial soils were chosen and a bottom soil was selected for the test area. By nature of its origin, its physical properties would probably be as variable as any encountered in the loessial group.

Study objectives were, 1) to determine the effects of spacing of observations on accuracy, and 2) to find out how many observations per sample were needed to estimate a property to desired accuracies. Thus, if spacing proved to not be a factor on this soil, it would be assumed that on less variable loessial soils, it would not be a factor, and, soil property measurements based on the number of observations determined necessary for any degree of accuracy, would result in just as good accuracy on similar loessial soils, and better accuracy on less variable soils.

In addition to strength measurements, Atterberg limits, bulk density, soil texture, soil moisture, and organic matter content were measured. On a 50- by 60-ft. plot, 120 observations were made in 3-in. increments down to 18 inches below the surface.

The major results of the study were:

1. Regardless of spacing interval, from 2-1/2 to 50 feet, accuracies of measurement of any property did not vary significantly.

2. Soil moisture variability was the same at 29.44 Mw and at field maximum (36.08 Mw).

3. In the 6- to 12-in. soil layer, changes in microrelief from 0.3- to 1.8-ft. could account for a large portion of the variation in soil moisture and density.

4. Increasing chances of being wrong from 1, to 10 times in 100, would allow sampling to acceptable accuracies with generally less than 20 observations.

Stearns, F. W., and Carlson, C. A.

1959 Some Correlations Between Solar Radiation and Other Environmental Factors and Soil Moisture Depletion. Journal Geophysical Research. (In Press).

The relationships of solar radiation and other factors with moisture loss were examined for the purpose of broadening the usefulness of soil moisture prediction methods. Data were obtained from an upland meadow site on loess in Mississippi. Relationships were examined by computing correlations between environmental factors and measured moisture loss. Correlations were calculated for three-day periods when soil moisture was in the upper half of its range, using drying periods only.

Highest correlations of single factors with moisture loss were obtained with soil temperature and evaporation pan data (r -0.79 each) with a slightly lower value for solar radiation (r -0.76) and progressively lower values for air temperature, vapor pressure deficit, and humidity. Correlations with soil temperature or evaporation were not vastly improved by adding other factors in combination or with curvilinear functions. The highest correlation for a single factor was obtained between the site derived depletion curve and measured moisture loss (r -0.85). Four radiometers were also evaluated.

Stearns, F. W. (Part I), and Rich, R. W. (Part II)

1959 Transition Date Determination as Related to Climate, Soil and Vegetation. Engineer Miscellaneous Paper. (In Process).

Transition dates between seasons are essential to the Vicksburg system of soil moisture prediction which depends upon the application of seasonal depletion curves. These dates were originally derived by inspection of the soil moisture record. Methods of estimation of transition dates have also been derived and include the application of average seasonal evapotranspiration levels to computed curves and the observation of phenologic condition of the vegetation of the area. In Part I these methods, the factors affecting transition dates and the methods of estimating are discussed and the resultant dates compared. Other approaches to the estimation of transition dates, primarily through the use of climatic data, are suggested.

Part II discusses a test of the effect of shifts in transition date on the accuracy of soil moisture prediction. Data from 7 sites including 17 site years were used in this test. The sites chosen fell along the 90th parallel from Vicksburg, Miss., to Rhinelander, Wisc., and were similar in that they were all wetness index II sites located on loam soils.

Results indicate that transition dates may be estimated from the record of the 6- to 12-inch depth only; the 0- to 6-inch depth is considerably less sensitive to shifts in date. Rainfall during periods of depletion rate change influences sensitivity of transition dates, in particular rainfall tends to delay the date of the change to summer and to hasten the shift to autumn. A method of computing dates is suggested and the computed dates used in the analysis. It was found that the spring to summer date must be estimated most accurately for satisfactory prediction accuracy (within plus or minus 5 to 10 days) while progressively greater leeway was permissable in estimating the spring, autumn and winter dates (winter dates may vary more than plus or minus 15 days without seriously influencing prediction accuracy).